1427983

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(54) COMPOUND BEARING FOR CONNECTING A HELICOPTER BLADE TO A HELICOPTER ROTOR

(71) We, UNITED AIRCRAFT CORPORATION, a Corporation organized and existing under the laws of the State of Delaware, United States of America, having a place of business at 400 Main Street, East Hartford, Connecticut, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed to be particularly described in and by the following statement:—

This invention relates to bearings which connect helicopter blades or blade connected parts to helicopter rotors or rotor connected parts and more particularly to a bearing which connects a helicopter blade to a lead-lag damper and which is compound in nature, which is partially elastomeric, which fits into an acceptable space envelope and which accommodates relative motion between the connected parts in at least three degrees of freedom, with one of those degrees of freedom being over a substantial motion range.

In the prior art, sliding element spherical bearings have been used to connect the blade end-shafts to the blade lead-lag damper but such bearings do not have the high degree of reliability of an elastomeric bearing in that they either require frequent lubrication or they wear out fairly rapidly, since the ball portion of the bearing moves from under the journal portion of the bearing during rotor operation, and any type of solid lubricant is lost in this fashion and foreign matter is drawn into the interface between the ball and journal. While the use of a spherical elastomeric bearing would provide the desired bearing reliability, such an elastomeric bearing would have to be of excessively large size to accommodate the amount of pitch change motion and the amount of misalignment between the blade end-shaft and the damper piston-rod caused by motion of the blade about the lead-lag axes and other motions. One of the limitations of an elastomeric bearing is that it can accommodate but a given degree of motion for a given bearing size without exceeding the limit for the elastomer shear strain, and thereby risking damage to the bearing.

It will accordingly, be seen that the conventional sliding element spherical bearing does not have sufficient reliability for a helicopter rotor head, and that a single elastomeric bearing would have to be of unacceptably large size to be able to accommodate the motion requirements of the blade.

A primary object of the present invention is to provide a compound bearing between a blade end-shaft and an associated rotor-connected lead-lag damper which will accommodate blade pitch change motion through a range of about 60 degrees and which also accommodates relative angular movement between the blade end-shaft and the damper piston-rod, and which can be contained within an acceptable space envelope.

In accordance with the present invention, the blade end-shaft terminate in a reduced diameter stub-shaft, a low friction journal bearing encircles the stub-shaft, and a part-spherical elastomeric bearing is connected between an outer sleeve of the journal bearing and the damper piston rod. The relative torsional freedom between the journal bearing and the elastomeric bearing is such that the journal bearing accommodates all blade pitch change motion and the elastomeric bearing accommodates all relative angular movement between the blade end-shaft and the damper piston rod.

Where the journal bearing comprises two concentric cylindrical sleeves, these are held in axial alignment, the inner one being connected to the aforesaid stub-shaft and the outer one being connected to an inner element of the part-spherical bearing, so that contaminates will not be admitted therebetween and so that lubricant or low-friction surfaces therebetween will remain unimpaired.

The compound bearing formed by the combination of the journal bearing and part-spherical elastomeric bearing is of minimal

size and the elastomer laminates which, in known manner, make up the elastomeric bearing, operate in acceptable shear strain condition.

Other objects and advantages of the present invention may be seen by referring to the following description read in conjunction with the accompanying drawings.

Figure 1 is a top view of a portion of an articulated helicopter rotor head using the invention and partially broken away for purposes of illustration.

Figure 2 is an enlarged view of a compound bearing connecting a blade lead-lag damper to the blade stub-shaft.

Figures 3A and 3B show a helicopter blade connected to the hub through the bearing, with Figure 3A showing the blade at its "at rest" or normal flight condition, and Figure 3B constituting a diagrammatic representation of the forces acting upon the blade at the moment of rotor start-up.

Figures 4A and 4B show the blade in an early stage of rotor start-up, with Figure 4A showing the position of the blade in this early stage of rotor start-up and Figure 4B illustrating the forces acting upon the blade during this early stage of rotor start-up.

Figures 5A and 5B correspond to Figures 4A and 4B but show the blade in a more advanced rotor start-up position and illustrate the forces acting thereon in this more advanced position of rotor start-up.

Figures 6A and 6B show the blade in its fully supported position during rotor start-up, with Figure 6A showing the blade so positioned, and Figure 6B diagrammatically showing the forces acting on the blade so positioned.

Figure 7 shows a droop stop which may be used with the bearing.

The present specification describes the same specific embodiment as co-pending applications Nos. 28753/73 and 29849/73 (Serial Nos. 1,427,982 and 1,427,984 but the invention defined in the appended claims is different from the inventions claimed in said co-pending applications.

Referring to Fig. 1 of the drawings, we see a portion of helicopter articulated rotor head 10 which comprises hub member 12 mounted for rotation in conventional fashion about the axis of rotation 14. A plurality of helicopter blades 16 are supported substantially radially from hub 12 for rotation therewith about axis 14 so as to generate lift for the helicopter in conventional fashion. It should be borne in mind that while a single blade is shown in the drawings, there are actually a number of such blades, possibly four. Hub 12 includes a chamber-defining housing 18 for each blade which defines blade attachment chamber 20 therewithin. Housing 18 is preferably substantially cylindrical and extends substantially radially with respect to axis of rotation 14. Housing 18 includes a mouth-shaped member 22 which defines a substantially circular opening 24 from chamber 20 and which also defines a part-spherical surface 26 of the outer bearing element of laminated part-spherical, annular, elastomeric bearing 28. Preferably, as shown in the drawing, the outer bearing element 22 is separate from and connected to housing 18 by conventional connecting means 30.

Blade 16 is connected to hub 12 by blade connecting means 32, which comprises shaft member 34 which is preferably positioned concentrically about the blade feathering or pitch change axis 36. An end portion 40 of the shaft member 34 comprises a flanged or mushroom-shaped portion 38 and a stub-shaft 72. The end portion 40 may be integral with shaft 34 or separate therefrom and connected thereto by conventional connecting means, not shown. Shaft 34 is connected to housing 18 through an annular elastomeric bearing 42, comprising a plurality of stacked discs as described below, connecting member 44, and annular part-spherical elastomeric bearing 28. Bearings 42 and 28 are preferably laminated as more fully disclosed in U.S. Patent specification No. 2,900,182 with flat bearing 42 being similar to that shown generally in Fig. 7 thereof and part-spherical bearing 28 being similar to that shown generally in Fig. 8 thereof. Part-spherical bearing 28 comprises a plurality of part-spherically shaped laminates which are alternately elastomeric and rigid material such as metal, and which are bonded together. The inner elastomeric laminate is bonded to part-spherical surface 46 of connector member 44. The part-spherical laminates and surfaces 46 and 26 are centered about the intersection of blade lead-lag axis 52 and blade flapping axis 50, which is perpendicular to axis 52, and which intersection also includes blade feathering axis 36. Bearing 42 consists of a stacked plurality of annular flat discs comprising alternately positioned elastomeric and metal disc members bonded together and with one end elastomeric disc bonded to end plate 54 and at the opposite end to plate 56, which may be an integral part of connecting member 44 or connected thereto by conventional connecting means such as bolt and nut mechanism 58. The elastomeric discs of bearings 28 and 42 may be made of natural rubber, while the rigid discs are made of steel or titanium. At its opposite end, shaft 34 supports sleeve 60 which, in turn, supports blade 16 for rotation therewith about feathering axis 36. Pitch control horn 62 is connected to sleeve 60 by conventional connecting means 64 and is connected at its opposite end to rod-end bearing 66 of the pitch control rod, which is connected at its opposite end in conventional fashion to conventional swash-

plate 68 so that swashplate motion causes the blades 16 to vary in pitch about axis 36 either collectively or cyclically.

It will therefore be seen that blade 16 is connected to hub 12 through sleeve 60, shaft 34, disc-type bearing 42, connector member 44 and part-spherical bearing 28, which connects to hub housing 18. It will be noted that the elements just enumerated, including bearings 42 and 28 are positioned in series relationship to one another.

A bearing 71, which is of the plain bearing type, is shown positioned between shaft 34 and member 44, however, it should be noted that this construction uses no centering bearing for bearings 42 and 28. The bearing 71 serves to carry the shear loads of the rotor across the bearing 42.

A lead-lag damper 70, which is of the hydraulic or pneumatic cylinder-piston type, connects to journal portion 72 of stub-shaft portion 40 of shaft 34 through bearing member 74 and serves to dampen the lead-lag motion of blade 16 about the lead-lag axis 52. Such a damper is provided for each blade.

With the rotor construction shown in Fig. 1, blade 16 is mounted so as to articulate with respect to hub 12 and has freedom of motion with respect to hub 12 about feathering axis 36 for pitch change motion, about lead-lag axis 52 for lead-lag motion, and about flapping axis 50 for flapping motion. The blade flapping motion, which has a range of about 30 degrees, and the blade lead-lag motion, which has a range of about 20 degrees, is accommodated by spherical bearing 28. The pitch change motion, which has a range of about 60 degrees, cannot be accommodated by any single, practically sized elastomeric bearing, and because part-spherical bearing 28 and annular bearing 42 are connected in series, these two bearings share the pitch change motion of the blade. During nomal rotor operation, part-spherical bearing 28 absorbs both the rotor in-plane shear loads and the rotor out-of-plane shear loads, while both bearings 42 and 28 react the blade centrifugal loading.

As stated previously, it is an object of the invention to provide a bearing in an articulated rotor which provides three degrees of freedom of the blade with respect to the rotor over substantial ranges of motion, and which can be contained within a minimal space envelope, thereby holding rotor weight and drag to a minimum. The prior art interlocking yoke design will not provide the minimal space envelope desired. It was therefore decided to pass the blade or its retainer through the bearing in an attempt to reduce the space envelope. While a single bearing construction might be utilized in a helicopter rotor having minimal blade motion as in the French Patent specification No. 934,336 it could not be utilized in a helicopter rotor having a lead-lag range of about 20 degrees, a flapping range of about 30 degrees, and a pitch change range of about 60 degrees. One of the limitations of an elastomeric bearing is the degree of motion which any one bearing can accommodate in any degree of freedom. To accommodate motion freedom over the extensive ranges referred to above would have required a tremendously large single elastomeric bearing, and this would be intolerable from a minimum space envelope and rotor drag and weight standpoint. It was realized that a part-spherical bearing would be needed to provide blade freedom of motion about the lead-lag and flapping axes, however, because such a part-spherical bearing tapers away from shaft 34 as shown at an angle θ so as to increase the space envelope required for the bearing, an objective of this invention is to keep the height h of the part-spherical bearing to a minimum, and thereby maintain the bearing space envelope at a minimum. It was decided that a part-spherical bearing sized only to accommodate the required lead-lag and flapping motion would be of minimum height and would also be capable of accommodating a portion of the required pitch change motion. It was further decided that the remainder of the required pitch change motion could be accommodated by an annular elastomeric bearing placed in series which would not increase the rotor space envelope.

An advantage of the in-series elastomeric bearing arrangement is that the torsional stiffness of bearings 28 and 42 can be controlled so that each bearing accommodates the proportional amount of pitch change motion desired to achieve the minimum rotor space envelope. The torsional stiffness of bearings 28 and 42 can be controlled by varying the size and thickness of the elastomeric laminates and by varying the durometer and shear modulus of the elastomer itself. The preferred stiffness ratio in the described bearing is 3:1 with bearing 28 accommodating 25% of the required pitch change motion and bearing 42 accommodating the remaining 75% of the required pitch change motion. Such a bearing stiffness ratio, while not essential to the bearing arrangement, provides the advantage of a minimal size part-spherical bearing 28, and thereby produces an arrangement of minimal space envelope.

Whether or not bearing 71 is required would depend upon the amount of rotor in-plane and rotor out-of-plane shear loads which must be passed through bearing 42 and the shear load capacity of bearing 42. In a low shear load situation, bearing 71 would not be necessary and it should be borne in mind that bearing 71 merely serves to carry the shear loads of the rotor across bearing 42 and is not a centering bearing for the elastomeric bearings 42 and 28 insofar as it does

not provide a fixed pivot for blade 16. In this bearing design, a centering bearing is not needed because bearing 28 provides the fixed pivot for blade 16 during normal operation. Larger excursions of blade 16 about the flap axis 50 and lead-lag axis 52 are restrained by the coaction of damper 70 and shaft 34 abutting fixed surface 24 of housing 18 or bearing outer race 22 so as to establish two hard points for blade support.

Lead-lag damper 70 is pivotally connected to hub 12 by conventional spherical joint 80 and is connected at its opposite end to the journal portion 72 of shaft 34 by bearing 74. Damper 70 is basically a piston member 82 within cylinder 84 and hydraulic fluid is selectively conveyed between chambers 86 and 88 through conventional chamber connecting mechanism 90 so that damper 70 serves to dampen blade lead-lag motion about lead-lag axis 52.

A unique feature of this construction is the bearing 74 used to connect damper 70 to the blade. To be consistent from a bearing reliability standpoint, with the remaining bearings of the system, it was decided to substitute an elastomeric bearing for the conventional spherical rod-end bearing between damper piston shaft 92 and the journal portion 72 of shaft 34. Because bearing 74 must be able to accommodate the pitch change motion of blade 16, together with other motions, and because this pitch change motion is as high as 60 degrees, it was not possible to use a single elastomeric bearing in this location within reasonable space limitations because, as previously mentioned, an elastomeric bearing of given size is limited with respect to the amount of torsional motion which it can accommodate. Accordingly, as best shown in Fig. 2, bearing 74 comprises two parts, an elastomeric portion 94 enveloping a journal bearing portion 96. The arrangement of these two bearing portions is such that bearing 96 accommodates all pitch change motion with respect to damper rod 92 and elastomeric bearing 94 accommodates all misalignment motion between the blade shaft 34 and damper piston rod 92. This misalignment motion which the elastomeric portion 94 of bearing 74 must accommodate is caused by the fact that as the blade moves in lead-lag motion, damper 70 is caused to pivot about its pivot point 80 and the center 98 of bearing 74 is caused to follow the arc described by the motion of center point 98 about the blade lead-lag axis 52, in other words, the arc between station 100 and 102 shown in Fig. 2. Accordingly, the angle between damper shaft 92 and blade 16 changes continuously between outboard ranges 100 and 102 as the blade moves in lead-lag motion and it is this change in angle between the damper shaft 92 and blade axis 34 which produces the misalignment in bearing 74 which the elastomeric portion 94 thereof must accommodate. All blade pitch change motion is accommodated in bearing 74 by the journal bearing portion 96 thereof due to its low friction or low stiffness quality when compared to the torsional stiffness of elastomeric portion 94. The elastomeric portion 94 of bearing 74 consists of outer bearing element 104, which is substantially a ring connected to or projecting from damper shaft 92 and having a part-spherical inner surface 106 positioned concentrically about bearing center 98. Elastomeric bearing inner element 108 is supported concentrically about journal portion 72 of shaft 34 by the journal bearing 96 and includes outer part-spherical surface 110, which is also centered about center 98. A plurality of part-spherical laminates of elastomer material and rigid material are alternately positioned between surfaces 110 and 106 and with the end elastomeric laminates bonded thereto and bonded to each other in spherical elastomeric bearing fashion. The elastomer laminates may be made of natural rubber and the rigid laminates may be made of steel or titanium.

The journal bearing 96 is a concentric sleeve arrangement with inner sleeve 114 which is connected by pinning or other convenient fashion to the journal portion 72 of shaft 34 and outer sleeve 116 is connected in some convenient fashion, such as pinning, to the inner element 108 of elastomeric bearing 94. The two sleeves 114 and 116 are of substantially U-shape cross section so as to be retained in concentric alignment about the axis 36 and to be relatively movable with respect to one another. Conventional retaining mechanism 118 serves to retain sleeves 114 and 116 on shaft 36. Sleeves 114 and 116 are preferably made of steel and Teflon (Registered Trade Mark) or carbon/ceramic.

The described construction of bearing 74 achieves a small envelope rod-end bearing which has improved performance over a conventional all elastomeric rod-end bearing. The reason for the improved performance is the reduction in the shear strain in the elastomer of bearing 74. This reduction in shear strain in the elastomer is achieved by eliminating the requirement of the elastomer to absorb pitch change motion, as would be required in a single elastomeric bearing. In addition, bearing 74 is superior to a spherical sliding bearing arrangement in this environment in that sleeves 114 and 116 are always in the same relationship to one another and therefore any solid lubricant or preferred bearing surfaces between the two parts remains intact and uncontaminated whereas, in the spherical bearing, the ball portion is intermittently exposed from the journal portion and any solid lubricant between the two is lost in this fashion and contaminates are admitted between the ball and journal.

It will therefore be seen that bearing 74 utilizes the best features of an elastomeric bearing in that the elastomeric portion thereof need not have large shear load carrying capabilities since it is not subject to pitch change motion, and the best features of a dry lubricated type of bearing since that portion of the bearing is a journal bearing and not the conventional spherical bearing.

Pitch control rod-end bearing 66 is preferably of the same construction as bearing 74 because it takes the same types of axial rotation and misalignment motions.

As is mentioned earlier, it is an important feature of the bearing construction, that a centering bearing is not used, thereby eliminating its attendant weight and mechanical complication. The previously identified French Patent specification No. 934,336 disclosed the concept of utilizing a spherical elastomeric bearing in a rotor head. However, there are certain operating conditions in a rotor, namely, the rotor starting and the rotor braking conditions, when the part-spherical elastomeric bearing needs assistance from other sources in carrying shear loads for reasons to be explained hereinafter. U.S. Patent specification Nos. 3,501,250 and 3,111,172 provided this assistance to the part-spherical elastomeric bearing by utilizing centering bearings together therewith. The centering bearings are heavy, tend to be complicated, and are utilized only during the short term regimes of rotor starting and rotor braking, and perform no useful function during the normal operation of the rotor. Further, space limitations may make the incorporation of a centering bearing difficult or impossible in the preferred embodiment. It is therefore an important teaching of this application to eliminate centering bearings by utilizing the blade-to-hub bearing combination taught herein. For an explanation of how the rotor is constructed so as to afford assistance to the part-spherical bearing 28 during the rotor starting and braking operation, reference will now be made to Figs. 3A and 3B to Figs. 6A and 6B. Considering Fig. 3A as initially representing the condition of the rotor during normal flight operation, part-spherical bearing 28 is under high centrifugal loading so that the laminates thereof are heavily compacted and have high shear load carrying capacity such that small angular deflections, due to lead-lag or flapping of the blade, are reacted by the part-spherical bearing 28. When the rotating rotor is braked, or when the rotor which is at rest is started, the centrifugal load is very low due to the slow rotor speed, yet the rotor torque is high due to the starting or braking rotor in-plane shear forces generated by the rotor changing speed and imparting that change to the blades. The low centrifugal force loading of the part-spherical bearing 28 causes the part-spherical bearing to lose its compaction and hence its good shear load carrying the capabilities and high in-plane rotor shear forces cause the bearing to yield laterally. We must accordingly compensate for this starting and braking condition situation and a description of the alternative to the use of a centering bearing will now be made.

Considering a rotor starting or start-up situation, wherein it may be considered that the rotor of Fig. 3A is at rest, when the rotor hub 12 commences to rotate, it imparts in-plane shear load F_S to the blade at the blade lead-lag axis 52 and the inertia of blade 16 imparts force F_I at the blade C.G while the lead-lag damper 70 imparts a damper load F_D in the direction shown in Fig. 3B. Lead-lag axis accordingly becomes the pivot point for blade 16 for loads F_D and F_I to act about and, due to the superiority of force F_I, the blade commences to rotate in a clock-wise direction about pivot point 52. Under this force balance condition, the blade will pivot clockwise to its Fig. 4A and 4B position wherein the blade has moved through the lag angle indicated and, because the forces acting on the blade have overcome the shear load carrying capability of part-spherical bearing 28 the bearing has yielded laterally and the blade centerline shifts laterally so that the blade center of flexure shifts from lead-lag axis 52 to station 130 as shown in Fig. 4B. The piston of damper 70 is being forced towards its bottom-out position as blade 16 moves from its Fig. 3A to its Fig. 4A position. As the clockwise motion of blade 16 continues beyond the Fig. 4A position, the blade will eventually bottom-out on lag stop 134, as shown in Figs. 5A and 5B and it will be noted that lag stop 134 is positioned radially outward or to the right of lag axis 52. This bottoming-out of the blade on lag stop 134 relieves, at least in part, the shear loading on the part-spherical bearing 28, and although the lag angle has increased between the Fig. 4 and 5 positions, the piston of damper 70 has not yet bottomed-out. As blade 16 now pivots about lag stop 134, the damper piston eventually bottoms-out so as to give the blade 16 two hard stops, namely, lag stop 134 and the bottomed-out damper 70, thereby completely relieving part-spherical bearing 28 of its shear loading. In practice, when blade 16 engages lag stop 134 in the Fig. 5 condition, the in-plane rotor shear load reaction shifts from the part-spherical bearing to the stop 134 and as the damper 70 bottoms-out as shown in Fig. 6 the blade centerline reverts to its original position so that blade 16 is again supported about the point of intersection of axes 36, 50 and 52, with the centerline of shaft 34 passing therethrough, blade lag motion stops suddenly and damper 70 loads and blade inertia peak at a very high point.

In the preferred embodiment, a centrifugally responsive droop stop mechanism is utilized of the form shown in Fig. 7. So as to limit the amount of droop which the blade can experience in its stopped or very low speed mode of operation, droop stop ring 160 is utilized. Ring 160 is slidably received on shaft 34 and is spring biased by spring member 162 to its operable position shown in Fig. 7, which position is assumed when the blade is at stop or at very low rpm. Positive stop ring 164 cooperates with spring 162 to position the land 166 of droop stop ring 160 to be in alignment with the surface of the bearing outer race 22 which defines droop stop and flap stop. Accordingly, when the speed of blade 16 is reduced a sufficient amount, spring 162 forces droop stop ring 160 against positive stop ring 164 so as to place land 166 into alignment with surface and thereby limit the amount of droop which the blade can experience between the operating regime shown in Fig. 7 and the regime in which land 166 contacts surface. When the helicopter rotor 10 starts up, and gains sufficient rpm, centrifugal force acting on droop stop ring 160 overcomes the force of spring 162 and forces droop stop 166 out of alignment with surface 134—136, thereby permitting greater flapping and lead-lag motion of the blade in flight than is permitted in droop motion when in the low rpm or stopped mode of operation.

It will therefore be seen that in the rotor start-up operation, as rotor starting torque is applied, the inertia of the blade causes the blade to begin to rotate about its lag axis. This lag motion will continue until such point that it is arrested by some means. If blade 16 were allowed to increase the lag angle in this fashion, damper 70 would eventually bottom-out and cause a rapid deceleration in blade motion about the lag axis which would cause very high impact loads to be placed upon the blade and rotor system. This very high impact loading is beyond the capability of part-spherical bearing 28 in shear, so we accordingly provide hard stop 134 to cooperate with the bottomed-out damper in carrying this load.

It will be evident that the loading on bearing 28 during the rotor braking operation is just the opposite of that shown in Figs. 3 to 6 which illustrate the rotor start-up operation, so that piston 70 bottoms-out at the opposite end of its stroke from the Fig. 6 showing and so that blade 16 bottoms out at lead stop 136.

It will accordingly be seen that the aforementioned French Patent specification No. 934,336 has a serious problem in the starting and braking modes of operation and that while U.S. Patent specification Nos. 3,501,250 and 3,111,172 utilize centering bearings, in combination with the spherical bearing to solve this problem, we have eliminated the need for the centering bearing thereby providing a lighter and less expensive construction.

WHAT WE CLAIM IS:—

1. A helicopter rotor having at least one blade adapted to be connected to a helicopter rotor hub, the blade including a blade-connected shaft mounted for rotary motion in response to blade pitch change motion and for pivotal motion about a blade articulation axis, a damper pivotally connected to the hub, and a bearing connecting said damper to said shaft, characterized in that said bearing includes a journal bearing encircling said shaft, and a part-spherical elastomeric bearing encircling said journal bearing and connecting an outer sleeve of the journal bearing to said damper so that said journal bearing and said part-spherical elastomeric bearing cooperate to accommodate blade pitch change motion and relative pivotal motion between the damper and the shaft.

2. A rotor according to claim 1, characterized in that said journal bearing includes an inner sleeve member journalled on to and connected to said shaft, said outer sleeve member being journalled on to said inner sleeve member for rotation with respect thereto with minimal friction, means to retain said sleeve members on said shaft in axial alignment, and that said part-spherical elastomeric bearing includes an inner element connected to said outer sleeve and having a part-spherical outer surface centered about a point on the shaft centerline, a part-spherical outer element enveloping the spherical inner element in spaced relationship thereto and connected to the damper member and having a part-spherical inner surface centered about said point on the shaft centerline, a plurality of part-spherical laminates positioned between said inner and outer elements and including alternate layers of elastomer material and rigid material bonded to one another and with the outermost elastomer laminate bonded to the outer element part-spherical surface and with the innermost elastomer laminate bonded to the inner element part-spherical surface.

3. A rotor according to claim 2, characterized in that said inner and outer sleeve members of said journal bearing are cylindrical in shape.

4. A rotor according to any one of claims 1 to 3, characterized in that means are provided to support said shaft member for motion about a lead-lag axis and a pitch change axis, said support means including a part-spherical bearing so as to permit universal movement between said shaft member and the hub about a selected point constituting the intersection of said lead-lag and pitch change axes.

5. A rotor according to claim 4, charac-

terized in that the blade is also supported from the hub for motion about a flapping axis, and that said lead-lag, flapping and pitch change axes intersect each other at a common point.

6. A rotor according to claim 1 and substantially as hereinbefore described with reference to and as illustrated in the accompany drawings.

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FIG. 1

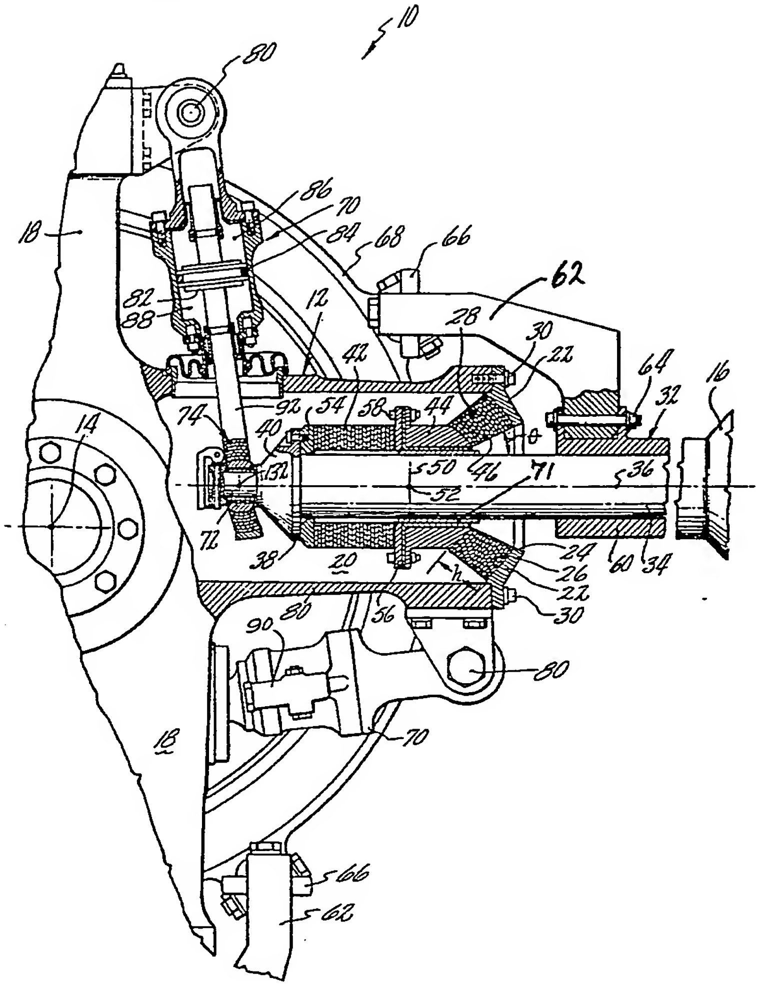
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FIG. 2

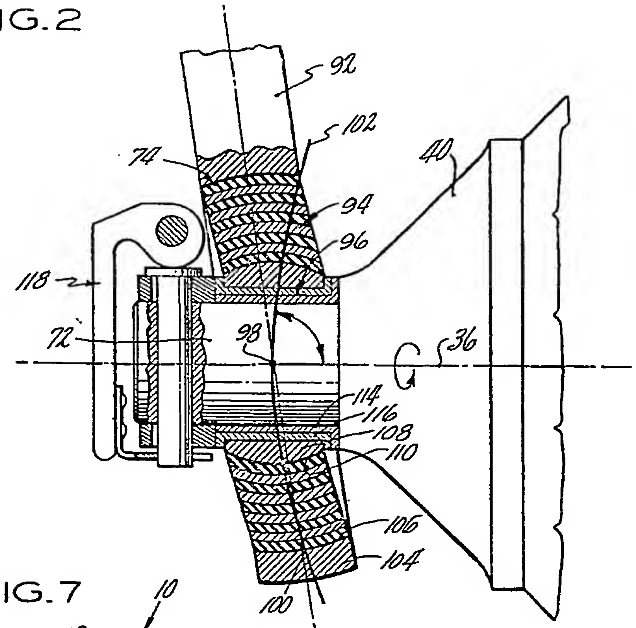
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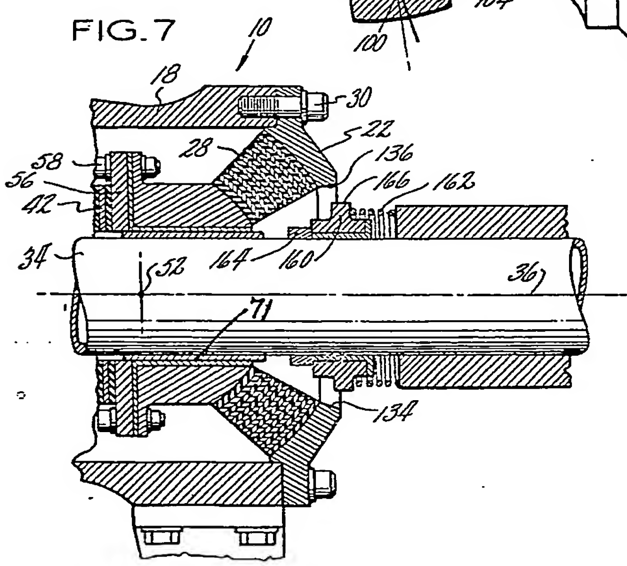
FIG. 7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164
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1427983 COMPLETE SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

FIG.3B (START-UP)

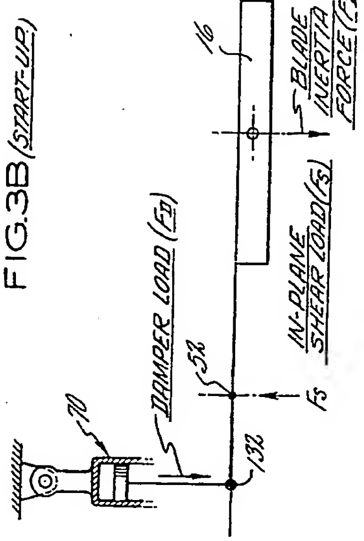


FIG.3A (REST)

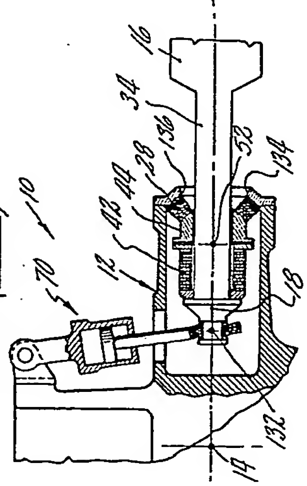


FIG. 4B

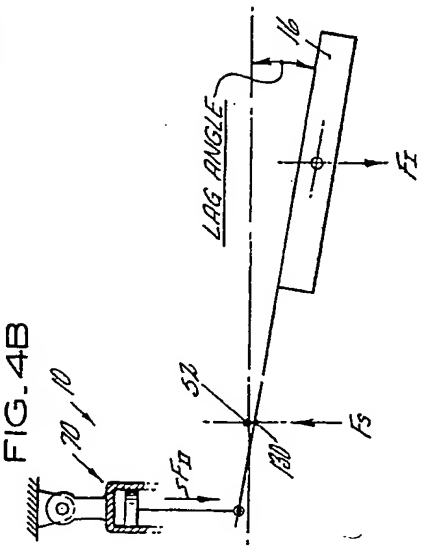
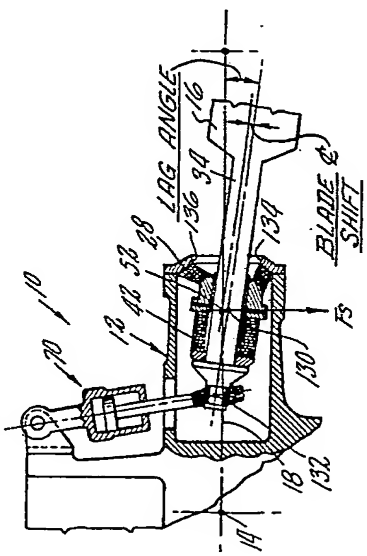


FIG. 4A



1427983 COMPLETE SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 4

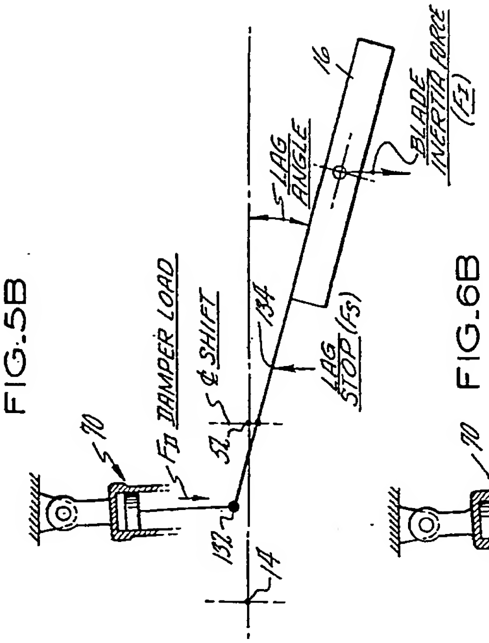


FIG.5B

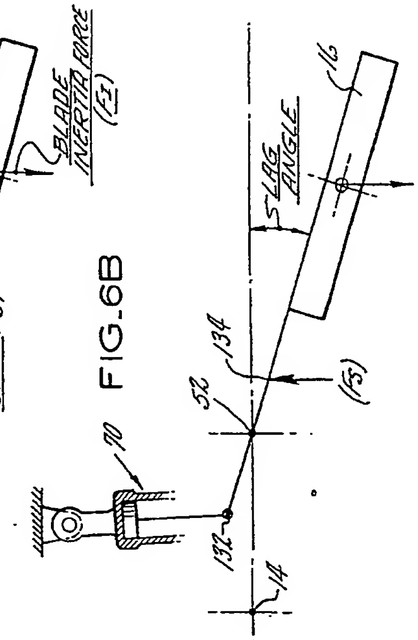


FIG.6B

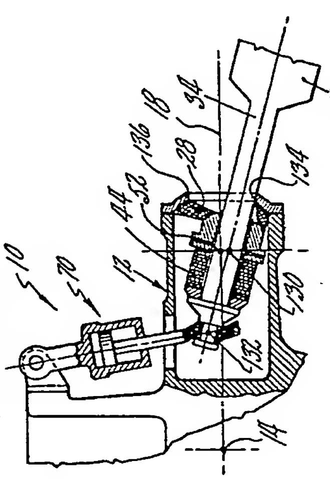


FIG.5A

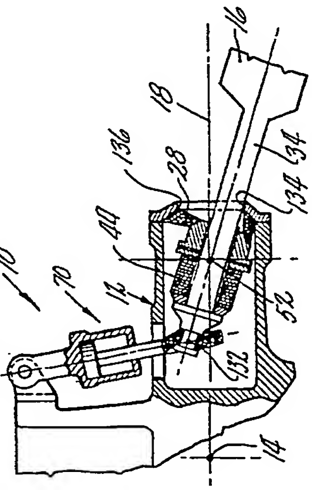


FIG.6A